COMPARATIVE CHEMISTRY OF HIGHER AND LOWER PLANTS.

BY HELEN C. DE S. ABBOTT.

(Concluded from page 730.)

THE laws controlling the chemical evolution of plant-constituents are too little comprehended to formulate, but before reaching a position ever to do this, it will be necessary to study carefully the facts from extended researches, to ascertain how these chemical constituents occur, under what conditions, and if these conditions are constant or variable, and to what may be ascribed the variability.

In speaking of chemical compounds I will describe them as occurring according to the botanical disposition of Heckel's table, which I use provisionally, since it is not probable that this presentation will be the ultimate or best way to introduce the subject. But I am not prepared yet to offer any other arrangement purely on a chemical basis; since the application of the chemical side of plant-life as one more evidence in favor of the hypothesis of evolution, is still too new to possess a literature of its own.

I have already referred to the protoplasm and starch, also to the large ash-percentages of some of the lower groups, and among the compounds commonly found in many plants tannin appears first according to the evolutionary order in liverworts.

Chlorophyll is one of the earliest compounds to appear, and its presence in Algæ and its absence in Fungi is a distinction between the two divisions of the Thallophyta group. Besides this green coloring matter, which is, with few exceptions, common to all plants, other brilliant coloring matters occur in some of these lower plant forms which are peculiar to whole families and correlated with special physiological functions.

The general distribution of chlorophyll, with few exceptions, in all plant groups is only second to the proteid compounds; however, the color of this compound is not the same tint in all plants, and the evergreens and many other plants when compared will be found in this respect distinct. The gradual change from the bright greens of the early spring foliage to the duller greens

of late summer illustrates the transmutation of color which may be observed in plants, and I would suggest that this same gradation may be seen on the large evolutionary planes of all plant groups, chlorophyll, like the plants, being at different evolutionary stages; for example, in many Algæ and lower plants it appears as light bright greens, and finally in the darker greens of the higher plants.

Considering in general the chemical compounds of flowering plants among the apetals and monocotyledons on the first evolutionary plane, where the plant elements are simple, tannin, wax, starch, aromatic or acrid principles, and the oils and sugar of the palm are the most conspicuous substances. These compounds are found in the same or in neighboring plants, and their association is doubtless of evolutionary significance. Glucosides or alkaloids, though occurring in some few of these plants, are not characteristic of this stage of evolution.

Tannin is a general name for a class of substances which presents many aspects in different plants. It first appears, as was stated, in the liverworts, combined with large quantities of starch and wax; then in ferns. Among the amental apetalous groups it is one of the conspicuous compounds, also associated with starch; the casuarina, willow, poplar, hazel, oak, beech, chestnut, alder, and birch containing large quantities. Tannin is widely distributed, though especially in the leaves, barks,[1] seeds, and rinds of fruits, and in other plants in considerable quantities, as the maple, sumach, tea, in many berries, the holly, and the seeds and stalks of the grape-vine.

Tormentilla erecta,[2] Rosaceæ, yields six to twenty per cent tannin, and, although this compound is present in mono- and dicotyledonous plants, it seems to be more prominent in the apetalous on the first evolutionary plane, and to occur less, if at all, in the highest plants. When it is remembered that tannin is found in greater abundance in lower plants, which I have compared as formative to the formed or higher evolutionary groups, it is a still further illustration of what was stated about the higher percentage of ash-constituents in lower plants.

Physiologists differ as to the tannin functions in plants. It

[1] "Repartition du Tannin dans les diverses Regions du Bois de Chene," Ann. de la Science Agr.

[2] Fraas, Ergebnisse, Landw. Versuche, München, 1861.

probably serves several purposes; according to Schell, as a plastic material for the building up of tissues, especially where starch or fats are absent; or it exists as a subordinate product. It is certainly true that some tannins play a distinct rôle as the source of many vegetable colors,—the reds and blues of flowers, the brown of tree-barks, and the colors of changing leaves owing their origin to this source.

The large quantity of starch in most tannin plants is remarkable, and Sachs believes it, or fixed oils, to be the mother-substance of tannin.

Datiscin,[1] a kind of starch, is found in the Datisca order, and, among the monocotyledons, the palms occur on the same plane, and in most of their genera contain large quantities of starch, eight hundred pounds of sago having been obtained from one plant of *Metroxylon*, or the sago-palm species. The *Arum pandanus* (screw-pine) and bulrush orders yield much starch; of the latter plants, 12.5 per cent. from *Typha latifolia* (Lecoq).

Large quantities of wax are found in species of the myrtle, and also of the palm.

On the second plane, or multiplicity of floral parts, the chemical constituents become much more numerous at this stage. Under the apetalous and monocotyledonous groups volatile, pungent, and aromatic principles, alkaloids, sugars, coloring-matters, camphors, resins, starch, and glucosides appear prominently. The lower dicotyledonous plants reproduce many of the compounds of the other two classes, for the Rosaceæ contain the tannins of the lower apetalous plants and its parallel groups, and the glucosides of the higher monocotyledons.

Cane-sugar is a prominent compound here. If a horizontal line be drawn from a given point of Heckel's scheme it passes through the apetalous, mono- and dicotyledonous groups, which contain this substance most abundantly,—namely, the sugar-beet, sugar-cane, sorghum, the fruit groups of the Rosaceæ, and the sugar-maple.

The sugar of the palms, among the highest of plants with simplicity of floral elements, is very like that of the cane. Since the grasses are the lower of monocotyledons with multiplicity of parts, it is notable that at the meeting-ground between these groups, or at the transition-stage into multiplicity, sugar should

[1] According to Stenhouse, datiscin is a crystalline glucosidal bitter substance.

occur. The sugar of the palm is very little above the sugar line; it may be considered, in an evolutionary sense, as passing to the cane-sugar of these other groups, and as forming the apex of a low triangle, the base being the sugar line already described. The large percentage of grape-sugar in the fig, *Ficus carica*, occurs in a class very nearly on a line with these cane-sugar plants.

Glucosides are more especially the compounds of the middle plane of plant development, and are found in the higher monocotyledons of this stage, in the lower and some of the higher dicotyledons, and less frequently in the highest of all plants, or under cephalization. The first appearance of a glucoside occurs in the apetalous groups of flowering plants, as quercitrin in *Carya tomentosa*, Juglandaceæ, or in other hickory varieties; then in the next following orders, as salicin and populin, of the willow and poplar; antiarin, of the Antsjar, or Upas-tree (*Antiaris toxicaria*); acorin, of the *Arum;* and coniferin, of the Coniferæ. Among the Lirioideæ groups many glucosides occur, especially saponin, and I have found this compound in species of the yucca, agave, and among dicotyledons in leguminous plants; besides, it is found in Rosæ and other parallel groups.

Saponin is also found in *Smilax*, a genus partaking somewhat of the nature of endogens and exogens, and serves to unite all the saponin groups;[1] and although this compound is widely distributed in plants, it is a significant fact that all the groups containing it belong to this middle evolutionary division.

Rosoll[2] has found saponin in the cell-sap of living roots of *Saponaria* and *Gysophila*, and I have elsewhere called attention to the solvent action of saponin on resins,[3] also on calcium oxalate. This property is of value to the plant not only by acting as a solvent of insoluble or slightly soluble compounds, and thus assisting it in obtaining food otherwise difficult of access, but also resins are found in nearly all the Lirioideæ, and the presence of this chemical class associated with saponin shows a physiological adaptation of importance to the plant. It may be recalled that the pink family is remarkable for its proportion of lime, and this element is frequently found in large quantities,

[1] "Chemical Basis of Plant Forms."

[2] Monatsb. Chem., v. 94; Jahresb. d. Chem., 1884.

[3] *Yucca angustifolia*, Trans. Amer. Phila. Soc.; Chemical Basis of Plant Forms, Jour. Franklin Institute.

as well as resins, in other saponin orders. Saponin may thus be called a constructive element in developing the plant from the multiplicity of floral element to cephalization of these organs.

Among the members of the higher groups of plants many of the preceding stages of chemical evolution are represented up to a certain point, when the plants acquire other chemical characteristics,—*i.e.*, indigo, hæmatoxylin, and other coloring-matters of the leguminous groups, and the dyes of the madder plant, give way to the alkaloids of the cinchona, the coffee, the atropa, and the strychnos orders, and to the organic acids of the valerian order, and the aromatic and volatile compounds of the Compositæ.

Alkaloids, though so widely distributed, are not found in the very lowest nor the highest plants. Their occurrence in fungi has been already noted. In flowering plants among the lower apetals, piperin, the alkaloid of Piperaceæ, occurs; also, alkaloids are found in the monimia, hemp, laurel, and amaryllis orders, and in colchicum; but they are exceptional in these lower groups, and belong properly to dicotyledons, where they are found in many orders.

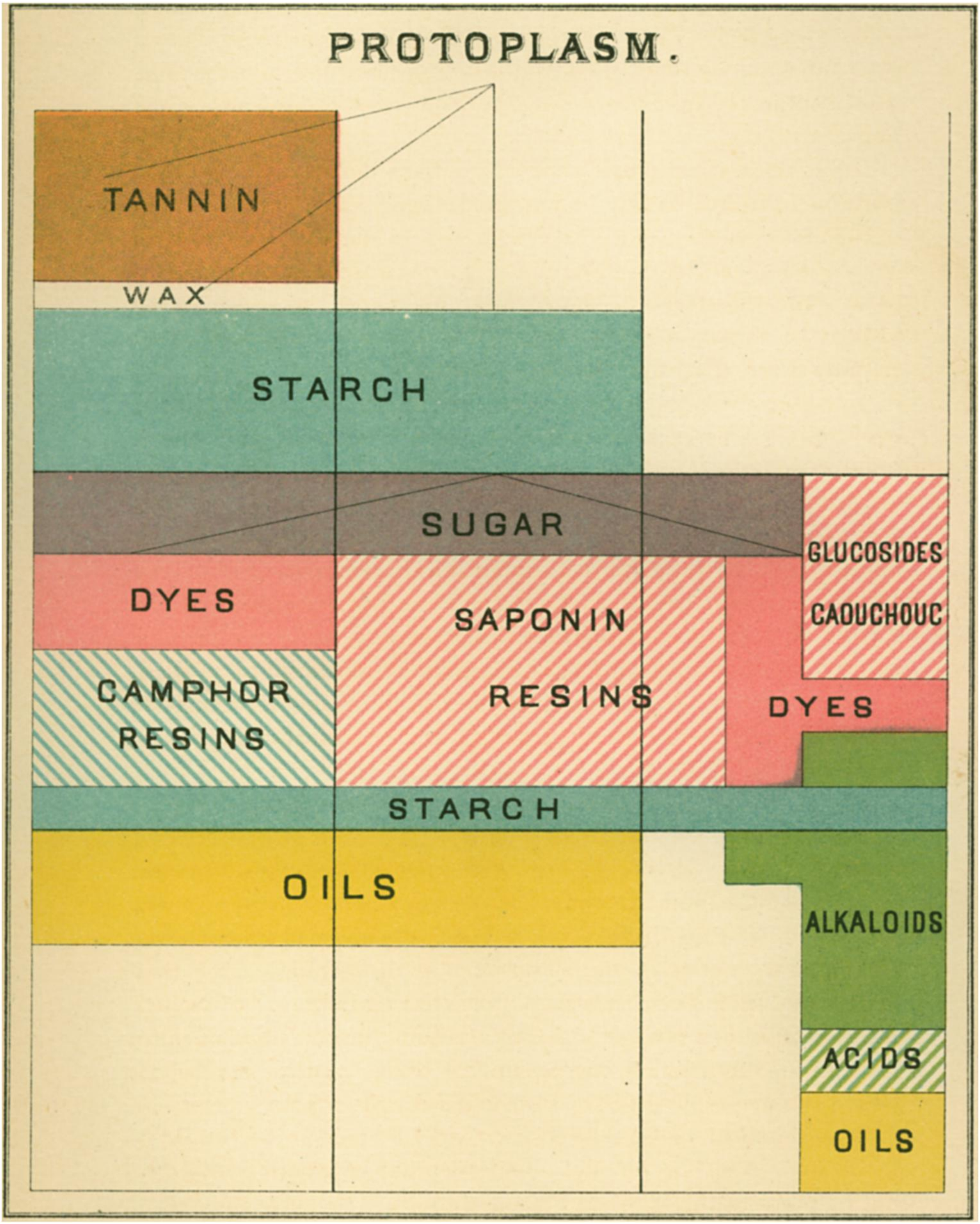
Besides the occurrence of compounds peculiar to distinct plants or whole plant groups, another class is found, and the substances of this class may be scattered quite generally through the plant kingdom, but always associated with some other compound.

Coumarin, the odorous principle of tonka-bean and vernal grass, is one illustration; its occurrence is limited to those plants containing oils, and, since in many genera in which this substance has been found certain fixed or ethereal oils also occur, it may be inferred that this constancy relates to their chemical evolution. The palms are the lowest plants which contain coumarin; then it occurs in the grass and rose families on the same evolutionary plane, also among the leguminous, madder, rue, and portulaca orders, and in orchids and Compositæ. These plants are characterized by their aromatic and volatile oily products; and vanillin, the fragrant principle of vanilla, also occurs among orchids. It may be noted that oils are formed abundantly in the highest plants.

A knowledge of the chemical compounds, as they are found grouped in plants, is a first step towards the study of their evo-

PLATE XXVII.

Plate II.



lution, and acquaintance with the conditions which control their synthesis and gradual formation in the plant can only be had by patient research. The simpler compounds of which any complex substance is built, if located as compounds of lower plants, would indicate the lines of progression from the lower to the higher groups.

It has been already said that every plant contains compounds peculiar to it, but certain compounds seem to play a special part in plant evolution, since the wax and tannin of the vascular cryptogams lead to the tannin and wax groups of the apetalous plants, and the starch of these lower plants to the great starch groups of the monocotyledonous. It will not be out of place to note here that the greatest accumulations of starch occur in plant orders just before they pass on to a higher plane of evolution. This is seen, for example, in the palm and neighboring orders of the first plane, and among the Lirioideæ of the second plane, since these plants are the richest in starch constituents, and it seems as if they were preparing by large reserves of food-supply for their higher position, represented by more evolved groups, where the demands for nutrition are greater. Again, the line of cane-sugar indicates that sugar occurs prominently in plants passing from simplicity to multiplicity of floral elements, and the glucosides in their turn are found in the middle stage of plant development, assisting the plants to the highest plane of cephalization.

Plate XXVII. is a chemical representation, drawn after Heckel's botanical table, and from what has preceded it will be easily comprehended. It is not to be inferred that all classes of chemical compounds found in plants are represented, since only a few have been used for illustration, nor that all of these given compounds only occur in the designated plant groups, since they may occur in traces or varying quantities elsewhere. However, these compounds are conspicuous as being especially typical of the plant groups which correspond to their location, and where their presence is doubtless associated with the plants' evolution.

The chemical compounds which may be said to be typical of an order, species, or an individual member of a series would be out of place in this general presentation.

Some plant groups, as the Proteaceæ, orchids, and Compositæ, develop in æsthetic beauty at the expense of their chemical con-

stituents, all resources go to develop the perfection of the flower, and the absence of numerous compounds in these plants is a strong point in favor of chemical evolution favoring plant development. These beautiful plants being among the highest of their series, may well be called the aristocrats of the vegetable kingdom.

It is still impossible to demonstrate the full significance of this chemical theory in plant development, but it will be evident to any one who examines botanical and chemical facts that the presence of certain chemical compounds is associated with certain botanical conditions, and where these conditions are variable, is found a like variability of chemical composition. If it can be proved that chemical and botanical morphology are not one and the same, at least the two are very intimately correlated.

It has been said that many of the constituents found in plants are the result of destructive metabolism, and are of no further use in the plant's economy, but our knowledge of what constitute plastic and waste products is by no means settled, and even should we be forced to accept the conclusion that some products are of no use to the plant, yet it is a significant fact that certain cell-tissues or organs secrete or excrete chemical compounds peculiar to them, and which are only to be found in one family, or in species closely allied to it.

Broadly speaking, the study of plant-life cannot be confined within the limits of the vegetable-cell, since its radiations reach to the domains of mineralogy and animal life. From a chemical point alone it would be difficult to discriminate in every case between the plant- and animal-cell. The series of animal-gums, carbo-hydrates, alkaloids, and coloring-matters find their analogous series in plants; by the study of embryology it is found that alantoin occurs in animal- and plant-life, also glycogen and inosite are found in both kingdoms, and the secretion of some plant-leaves is a fluid chemically like the animal gastric juice.

M. Leo Errera,[1] in a recent paper on a fundamental condition of equilibrium of living cells, calls attention to the thin and plastic condition of plant- as well as animal-cells at the moment of their formation, and their tendency to assume a form which, under the same conditions, an imponderable lamina of liquid would take, and he attributes to this fact their adaptability and the facility

[1] Comp. Rend., t. xiii., 1886, p. 822.

with which they change. He believes that we can trace to this cause the great number of organic forms, and for the first time unite the architecture of the cell to molecular physics. Only with age the cell-membrane becomes thick and offers a considerable resistance.

It may be suggested that this fact is further exhibited when applied to the conditions obtained when plants pass from their younger to older stages; again, it is seen on comparing the lower plastic protoplasmic plants with the rigidity and firmness of the tissues of the higher plants, and in the change from the semi-fluid to the formed and fixed states of chemical compounds.

The law of progression is one that regards the general good to the disregard of the individual; since in the death or fixation and crystallization of individuals the vegetable kingdom, on the whole, has ascended to its highest present living form, and many of its constituent chemical parts had long ago reached their pinnacle in the cycle of evolution. This concerns equally the changes in the vegetable-cell, and its complex molecule of proteid is built from simple substances, which in turn break down into less complex bodies, and are again reconstructed into proteids, or as cellulose and other compounds remain as the component parts of tissue in higher plants, thus serving the mechanical and physiological needs of the organism.

Aside from the practical application of plant products to dietetics, pharmacy, and the industries, it is eminently for purposes of scientific investigation that the field of plant chemistry is most promising.

It has been suggested to me from botanical sources that time will be unwisely expended over a detailed study of the chemical compounds of plants; in this, as in mineralogy, its use as a means of classification will depend upon the convictions of the investigator, although it seems to me that many of the vexed questions of plant development can only be solved by a full comprehension of vegetable chemistry.

It is not to be inferred that "botanists," the knights of morphology and systematic classification, will thereby be deprived, by chemists, from tilting over the floral tournament courts. Perhaps in such pleasant pastimes of contest for disputed plant groups this veteran army of knights-errant may at least become weary, and willingly exchange the lance for the balance.

The vegetable kingdom is so vast that the botanico-chemical facts at our disposal are meagre in comparison to the data required, and in consequence many of the explanatory statements advanced can only be considered in the light of speculation. Vistas have opened most promisingly but to be cut off suddenly by a limitation of these details, and I cannot urge too strongly the very great importance of minute chemical research at least in certain typical members of botanical groups; without such investigation a great deal of our present knowledge is worthless. The changes of the chemical compounds within the cell, the simultaneous appearance of two or more compounds always in association, and the predominance of some one compound in certain plant groups, should be seriously considered before the evolution of plant chemistry be definitely approved or condemned. These facts suggest questions which must be answered before a further advance can be made in plant biology.

The practical application of a theory, which advocates that the morphology of a plant is the outcome of its chemistry, will be used by the chemist to direct him to certain plant groups for any compound which experience proves to be present with similar morphological characters in other groups.

It has been recently suggested[1] that many of the chemical compounds may serve the plant as means of defence against animals, and when we camphorize our furniture and poison our flower-beds, we are only imitating and reinventing what the plants practised before the existence of man; and I may add that the cinchona-tree of malarial countries proclaimed long since their subtle therapeutical skill in securing for themselves a corner in quinine manufacture, independent of contemporary sources.

A full acquaintance with the chemical compounds of living plant orders may even lead to a chemistry of paleo-botany, and where the fossil forms resemble modern groups, as in some of the well-preserved remains lately discovered in France,[2] the same chemical compounds might have existed as are now found in similar groups. From the knowledge which will one day be ours of the morphology and evolution of chemical substances, a flora may be reconstructed reaching far back into the recesses of time.

[1] M. Léo. Errera, Royal Bot. Soc. of Belgium, Revue Scien., 29th Jan., 1887.

[2] M. Louis Crié, Comp. Rend., t. ciii. p. 1143.

In minerals, plants, and animals the same principles recur, though at each higher plane under more complicated conditions; and any one who, on visiting the Hot Springs of the Yellowstone National Park, has seen the non-carboniferous gelatinous masses assuming the forms of organized life will ask himself if silica, under some conditions, may not replace carbon and become living matter. Since Confervæ do live in these springs at high temperature, perhaps some such locality as the Yellowstone may have been the birthplace of "a protoplasmic primordial atomic globule."

The impulse which directs minerals to masquerade as living plants and animals often manifests itself, for example, in the ferns called stag-horns; and orchids, disguised like insects, pretend to be what they are not. When will all of these intricacies of nature's secrets belong to commonplace facts? The day is distant. And in the mean time my hour is drawing to a close; and, to return to my first statement of the evolution of the chemical elements, I would say that the studies[1] of Lecoq de Boisbaudron, Auer, Demarçay, and Crookes on didymium, and the latter's researches on yttria, and more recently on the crimson line of phosphorescent alumina,[2] go to show that the molecules of these so-called elements are compound, and if I have dwelt at all upon this subject, in connection with plant-life, it is on account of the indisputably serious nature of the investigations in this field. On listening to the following concluding remarks of Professor Crookes's address[3] the chemical evolution of plant compounds receives an able ally. He says, "We cannot venture to assert positively that our so-called elements have been evolved from one primordial matter, but we may contend that the balance of evidence . . . fairly weighs in favor of this speculation. . . . The doctrine of evolution, as you well know, has thrown a new light upon and given a new impulse to every department of biology, leading us, may we not hope, to anticipate a corresponding wakening light in the domain of chemistry. I would ask investigators not necessarily either to accept or reject the hypothesis of chemical evolution, but to treat it as a provisional hypothesis; keep it in view in their researches, to inquire how

[1] Comp. Rend., t. civ., 1887, p. 165, M. Henri Besquerel.

[2] Chem. News, Jan. 21, 1887.

[3] Delivered before the British A. A. S., 1886.

far it lends itself to the interpretation of the phenomena observed, and to test experimentally every line of thought which points in this direction."

From the above sketch I have attempted to show that the hypothesis of evolution may also apply to the chemistry of plant compounds, and that plant chemistry will be found, like any special study, to include many others. It is, however, exceptional in its broad range, and the variety of its topics, like the variations of flower-species, may be cultivated to suit the taste of the investigator.

INSTRUCTION IN GEOLOGICAL INVESTIGATION.

BY WILLIAM MORRIS DAVIS.

Revised from a paper read before the Association of American Naturalists in Philadelphia, December, 1886.

INSTRUCTION in geological investigation is so new a department of teaching that it is little assisted or hampered by traditional methods. Its best materials are found in the wide outdoor laboratory, and as all out-door laboratories are of their own local kind, every teacher is required to develop his own methods of using them; and he must count this to his advantage, for it prevents him from doing his own work in some other person's way. The personality of the teacher must appear here if anywhere; and it must be strongly flavored with the local problems that spring up around him in new crops every year, and with his own methods of attacking them. Instruction in geological investigation at any one place cannot therefore hope to reach the completeness that may be attained in physics or chemistry, where experiments are made to order in-doors, limited rather by the funds than by the place of the laboratory. Consequently, one of the first aims of the instructor, and of the student too if he take a proper share in laying out his own course of work, should be to see that his geological studies are pursued under more than one teacher and in many more than one place. So distinct is this need, and so strong do I feel the limitations that determine it, that I shall not presume to talk up to the general title suggested by the committee in charge of our meeting, but shall at